PCT/IL 99/00538

STATE PF ISRAEL

REC'D 10 NOV 1999	
WIPO	PCT

IL 99/538
4

This is to certify that annexed bereto is a true copy of the documents as originally deposited with the patent application particulars of which are specified on the first page of the annex.

זאת לתעודה כי רצופים בזה העתקים נכונים של המסמכים שהופקדו לכתחילה עם הבקשה לפטנט לפי הפרטים הרשומים בעמוד הראשון של הנספח.

This 17 -10- 1999 היום

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

רשם הפטנטים
Registrar of Patents

נתאשר

חוק הפטנטים, התשכ"ז–1967
PATENTS LAW, 5727-1967

בקשה לפטנט
Application for Patent

לשימוש הלשכה
For Office Use

מספר: Number	126962
תאריך: Date	09-11-1998
הוקדם/נדחה Ante/Post-dated	

אני, (שם המבקש, מענו – ולגבי גוף מאוגד – מקום התאגדותו)
I (Name and address of applicant, and, in case of a body corporate, place of incorporation)

MAKOR ISSUES AND RIGHTS LTD
32 YEHUDA ST
JERUSALEM ISRAEL 93467

מקור הנפקות וזכויות בע"מ
רח' יהודה 32
ירושלים 93467 ישראל

TEE 972 - 2 - 6734913 טל.
FAX 972 - 2 - 6734859 פקס.

בעל אמצאה מכח BYLAW ששמה הוא:
Owner, by virtue of BYLAW of an invention, the title of which is:

(בעברית) (Hebrew) תהליך לאופטימיזציה בתכנון כבישים

(באנגלית) (English) OPTIMIZATION PROCESS FOR ROADS PLANNING

hereby apply for a patent to be granted to me in respect thereof.
מבקש בזאת כי ינתן לי עליה פטנט.

* בקשת חלוקה – Application for Division	* בקשת פטנט מוסף – Application for Patent of Addition	* דרישת דין קדימה Priority Claim		
מבקשת פטנט from Application No. ____ מס' dated ____ מיום	* לבקשה/לפטנט to Patent/Appl. No. ____ מס' dated ____ מיום	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
* יפוי כח: כללי/מיוחד – רצוף בזה / עוד יוגש P.O.A.: general / specific – attached / to be filed later – Has been filed in case ____ הוגש בענין				
המען למסירת הודעות ומסמכים בישראל Address for Service in Israel מקור הנפקות וזכויות בע"מ רח' יהודה 32 ירושלים 93467				

חתימת המבקש
Signature of Applicant

D.My

מקור הנפקות והזכויות בע"מ
MAKOR ISSUES & RIGHTS Ltd.

היום 8 בחודש נובמבר שנת 1998
This 8 of NOVEMBER 1998

לשימוש הלשכה
For Office Use

תהליך לאופטימיזציה בתכנון כבישים

An optimization process for roads planning

Inventor:
Makor Issues and Rights Ltd
32 Yehuda St
Jerusalem 93467, Israel
Tel: 972-2-6734913
Fax: 972-2-6734859
Email: harhoma2@actcom.co.il.

Attorney, Agent or Firm:
Stanley Portigal. Patent law attorney
2519 Dexter Av. North, #C
Seattle, WA 98109
Tel. 206-217-0087
Fax 206-217-0087
Email: k269@scn.org
http://www.scn.org/~bk269.

DESCRIPTION OF INVENTION:
An optimization process for roads planning.

INVENTOR:
Makor Issues and Rights Ltd
32 Yehuda St., Jerusalem 93467, Israel
Tel: 972-2-6734913,
Fax: 972-2-6734859
Email: harhoma2@actcom.co.il

ASSIGNEE:
Makor Issues and Rights Ltd.
32 Yehuda St., Jerusalem 93467, Israel
tel: 972-2-6734913,
fax: 972-2-6734859
Email: harhoma2@actcom.co.il

Attorney, Agent or Firm:
Stanley Portigal. Patent law attorney
2519 Dexter Av. North, #C Seattle, WA 98109
Tel. 206-217-0087; fax 206-217-0087;
http://www.scn.org/~bk269; e-mail: bk269@scn.org

ABSTRACT:

Using optimization process, through linear or nonlinear programming, to obtain the optimal: points of intersection, vertical alignment of roads and lots, cross-sections, quantity, cost estimation and work program of excavation material transportation for the entire roads system and subdivision, according to topography, geology, roads standards and earthworks prices. This invention utilizes the information generated by a computer-aided design (CAD) program as input to the optimization algorithm.

14 Claims, 4 Drawing Sheet

BACKGROUND OF THE INVENTION:

Before the present invention the design for the roads was done separately for each road in the system. The design of a roads system usually began with the planning stage where the civil engineer arranges the road to satisfy the standard specifications such as grade and meeting of centerlines at intersections. Then a draftsman produces an initial design using one of numerous software programs to draft profiles, vertical alignment, and cross-sections, calculate the cut-and-fill quantities. Usually the initial design needs to be rearranged numerous times by the engineer to satisfy all of the physical constraints. This iteration may be repeated numerous times before the road system satisfies all of the physical constraints and balance the cut-and-fill quantities. The design has been typically

a trial and error affair according to the experience of the civil engineer. The vertical alignment is draft for one road at a time and not for the entire roads system. The retaining wall cost was not taken into account. The geologic data was not taken into account. Earthworks of subdivision lots were not taken on account. The economical factor was not taken on account. The optimization approach was not be used for roads design.

OBJECTS OF THE INVENTION:

The object of this invention is to develop a process of road design that arranges optimally geometry of roads system that satisfies the roads standard applicable into the most economical entity.

The object of this invention is also to develop a process to compare different layouts and different unit prices to obtain the cost-effectiveness in the preliminary planning stage.

DESCRIPTION OF THE INVENTION:

The optimizing modeling system establishes a direct relationship between the current economic conditions and the status of the roads designing system as a technical entity. The information includes topography, geologic data, roads centerlines plan, roads cross-sections, lots cross-sections (optionally) and earthwork units prices. This invention utilizes the information generated by a computer-aided design (CAD) program as input to the optimization algorithms (**Fig. 1**).

The optimization is reached by three methods that differ each from other by number of variables, time of performance:

a. **Grid optimization (Nonlinear programming approach)** - appropriate for inhomogeneous topography, when geological data is available and desirable and in the roads system exist fixed points (see paragraph 5). The optimization is obtained in one phase. This approach is time consuming because it handles many variables.

b. **Centerline optimization (Linear programming approach)** - appropriate for homogeneous topography, when geological data is not available or desirable. The objective function represents difference between cut and fill. The optimization is obtained in two phases. This approach is time consuming.

c. **Centerline optimization (Nonlinear programming approach)** - appropriate for Homogeneous topography, when geological data is not available or desirable. The objective function represents sum of unsigned differences between proposal and existing elevations along centerlines. The optimization is obtained in two phases. The result is obtained faster.

1. Grid optimization (Nonlinear programming approach):

The optimization is reached through nonlinear programming when objective is earthworks total cost. Variables are differences between proposal roads elevations and existing topography elevations at all grid points on right of way. Constraints are present roads standards.

Grid points (GPs) are 3D points at nodes of rectangular grid of definite size (e.g. 5m x 5m) that located on right of way. Boundary grid points (BGPs) are GPs located on edges of roads, i.e. points for which distance to road centerline is equal to half of road width (with some tolerance). BGPs are considered for retaining walls estimation.
Control points (CPs) are 3D points on proposal centerlines of roads system (e.g. for each 100m). CP might not be GP. **(Fig. 2).** Grade of road can be changed only at CPs. **Coordinates X and Y of CPs and GPs are entered as input data and coordinates Z are an output of optimization procedure.** Recommended locating CPs at points of centerlines where grades of existing profile are changed. This will improve optimization process. Using CPs and GPs elevations as decision variables we now define the nonlinear programming task:
Let Q(X'q,Y'q,Z'q) be a GP. Therefore Q lies on some road of given roads system. Then there must exist A(Xa,Ya,Za) and B(Xb,Yb,Zb) - adjacent CPs on this road centerline so that Q is located between A and B. It means that if Q' is nearest to Q point on road centerline including A and B, then Q' is located between A and B. Points Q and Q' must have same elevations. Therefore for any point Q from GPs exist λ, $\mu \in [0,1]$ so that:
$Z'q = \lambda * Za + \mu * Zb$,

Where
Z'q, Za, Zb are proposal elevations of points Q, A, B respectively.

If interval AB is straight then $\lambda = (\mathbf{AQ},\mathbf{AB})/(\mathbf{AB},\mathbf{AB}) \in [0,1]$,
$\mu = 1 - \lambda$.
It means that each GP proposal elevation may be received via linear interpolation from proposal elevations of corresponding pair of CPs.
Let
$Zq = Z'q - Ze$, where Z'q is proposed elevation and Ze is existing elevation at point Q. Zq is relative elevation at point Q. Zq is a decision variable and used in the objective function.

Objective is earthworks total cost:

$$(1.1)\quad \sum_{q=1}^{q=N} (Fq(Zq)*G+ Wq(Zq) + Cq(Zq)*G + Vq(Zq))*G + D$$

where
G is grid size (e.g. 5m);

$Fq(Zq)$ is cost of fill at point Q, where proposal GP elevation is bigger than existing GP elevation ($Zq>0$);
$Wq(Zq)$ is cost of retaining wall for fill at point Q, where proposal GP is above existing GP ($Zq>0$);
$Cq(Zq)$ is cost of excavation at point Q, where proposal GP is below existing GP ($Zq<0$);
$Vq(Zq)$ is cost of retaining wall for excavation at point Q, where proposal GP is below existing GP ($Zq<0$);
D is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.
If $Zq < 0$ then $Wq(Zq) = Fq(Zq) = 0$; also if Q is not BGP then $Wq(Zq)=0$;
If $Zq > 0$ then $Cq(Zq) = Vq(Zq) = 0$; also if Q is not BGP then $Vq(Zq)=0$.
The different cost functions that comprise the overall total earthworks cost are now detailed.
Let price of fill = f0 (money unit / volume unit), then $Fq(Zq)$ could be written so:
$Fq(Zq)= 0.5*f0*(|Zq| + Zq)$,
Hence, if $Zq < 0$ then $Fq(Zq) = 0$.
If excavation price is constant=c0, then
$Cq(Zq) = 0.5*c0*(|Zq| - Zq)$.
Hence, if $Zq > 0$ then $Cq(Zq) = 0$.
If excavation price depends on Zq (e.g. due to different geology layers), prices may be entered as a table:
for $0 > ajq > Zq > bjq$ corresponding price is Pjq and then

$$Cq(Zq) = 0.5 *\Big(\sum_{j=1}^{j=Kq}(|Zq - ajq| + ajq - |Zq - bjq| - bjq) * Pjq +$$
$$+ (|Zq - bKq| - (Zq - bKq))*Pqmax.$$

If $Zq > 0$, then $Cq(Zq) = 0$.
Kq is number of levels of excavation price at the point Q,
ajq, bjq – upper and lower depths of j-th layer at point Q,
Pjq – excavation price of j-th layer at point Q (order of layers may be depends on Q).
Pqmax is excavation price for $Zq < bKq$. (Here Zq, ajq, bjq, $bKq < 0$).
If Q is BGP, then

$$Vq(Zq) =0.5*\Big(\sum_{j=1}^{j=M}(|Zq - ej| + ej - |Zq - fj| - fj)* Fj +$$
$$+(|Zq - fM| - (Zq - fM))* Fmax),$$

where
for $0 > ej > Zq > fj$ corresponding price of retaining wall for excavation is Fj.
M is number of levels of wall for excavation prices.
Fmax is excavation wall price for $Zq < fM <0$.

If $Zq > 0$, then $Vq(Zq) = 0$.

$$Wq(Zq) = 0.5*\left(\sum_{j=1}^{j=L}(|Zq - cj| - cj - |Zq - dj| + dj)*Wj + (|Zq - dL| + (Zq - dL))*Vmax\right),$$

where

for $0 < cj < Zq < dj$ corresponding price of retaining wall for excavation is Wj:
L is number of levels of fill wall prices. Wmax is wall price for
$Zq > dL$.
If $Zq < 0$, then $Wq(Zq) = 0$.
Finally

$$D = 0.5*G*G*\left((I*\left(\sum_{q=1}^{j=N} Zq + \left|\sum_{q=1}^{q=N} Zq\right|\right) + O*\left(\left|\sum_{q=1}^{q=N} Zq\right| - \sum_{q=1}^{q=N} Zq\right)\right),$$

I – price of bringing of lack fill from other site to roads system area;
O - price of removing of redundant fill outside of the roads system area;
N is total number of GPs on roads system.
Constraints include five sets:

a) Constraints of road surface

$$Z1 = \lambda1*Z'1 + \mu1*Z''1 - Z1e + \lambda1*Z'e + \mu1*Z''e,$$
$$Z2 = \lambda2*Z'2 + \mu2*Z''2 - Z2e + \lambda2*Z'e + \mu2*Z''e,$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$ZN = \lambda N*Z'N + \mu N*Z''N - ZNe + \lambda N*Z'e + \mu N*Z''e,$$

Where
Zq is still decision variable that means relative elevation at $Q \in$ GPs for $q=1,\ldots N$;
Z'q and Z"q are differences of Z coordinates (proposal – existing) of adjacent CPs so that point Q is located between them;
Zqe is existing elevation at point Q.
Z'e, Z"e are existing elevations at adjacent CPs.
λq, μq are coefficients of linear interpolation of proposal elevation at point Q. Normally there are more than two GPs on each interval between CPs. Therefore Z'q and Z"q can be linearly expressed via each pair Zq1 and Zq2 (except case: $\lambda q1=\lambda q2$; in this case need use other pair). This allows eliminate Z'q and Z"q from surface constraints. Hence elevations of CPs are not used in these constraints directly. Instead of them are used their linear expressions via elevations of GPs that belong to the interval between two adjacent CPs. However these GPs are all located from one side from CP. This obliges introduce additional constraints:

b) CPs relation constraints:
Above mentioned linear expressions for Z'q and Z"q via pairs of Zq must be equal to such linear expressions for both adjacent intervals of CPs respectively.

c) Constraints of allowable grades (separately for CPs near to intersection (e.g. 50m)

and for other CPs):
$| H' + Z' - (H + Z) | / D < S$,
for all pairs of adjacent CPs;

where
H', H existing elevations of pair of adjacent CPs ,
Z' , Z are relative elevations of these CPs; instead Z' and Z implicit their linear expressions via corresponding Zq of GPs;
D is distance along the road between these CPs;
S is maximal allowable grade for road, or for intersection (e.g. S = 10% or 6%).

d) Constraints of intersections: (elevations of intersection points of different roads must be same).
$H + Z - (H'+ Z') = 0$,
For all CPs at intersections; instead Z' and Z implicit their linear expressions via corresponding Zq of GPs;
Where H, H' are existing elevations at the intersection CPs.

e) Constraints for lack or excess total fill or excavation volumes:

$$\sum_{q=1}^{q=N} Zq > 0 \text{ or } \sum_{q=1}^{q=N} Zq < 0,$$

The objective function (1.1) contains absolute values. Those absolute values can be transformed into linear form.
In case of

$$\sum_{q=1}^{q=N} Zq > 0, \text{ i.e. fill} > \text{cut}, \quad (1.2)$$

the objective (1.1) is reduced as follows:

$$\sum_{q=1}^{q=N} (Fq(Zq)*G + Wq(Zq) + Cq(Zq)*G + Vq(Zq)) + 2*G*I * \sum_{j=1}^{j=N} Zj.$$

Equation (1.2) obviously must be joined to constraints.
Then substitute for each $Zq - ai$, $Zq - bi$, $Zq - cj$, $Zq - dj$, $Zq - ej$, $Zq - fj$
new variables:
(*) $Zq - ai = Uqai1 - Uqai2$, $i=1,\dots,Kq$,
(*) $Zq - bi = Uqbi1 - Uqbi2$, $i=1,\dots,Kq$,
(*) $Zq - bKq = UqbK1 - UqbK2$;
(*) $Zq - cj = Uqcj1 - Uqcj2$, $j=1,\dots,L$,
(*) $Zq - dj = Uqdj1 - Uqdj2$, $j=1,\dots,L$,
(*) $Zq - dL = UqdL1 - UqdL2$;
(*) $Zq - ej = Uqej1 - Uqej2$, $j=1,\dots,M$,
(*) $Zq - fj = Uqfj1 - Uqfj2$, $j=1,\dots,M$,

(*) Zq - fM = UqfM1 – UqfM2.
In objective instead | Zq –ai | substitute Uqai1 + Uqai2 etc. So is got LP task because all constraints are linear. All constraints also do not include Zq, but only their expressions via Uq…1,Uq…2.

For example, nonlinear form of Cq(Zq):

$$Cq(Zq) = \sum_{j=1}^{j=Kq}(| Zq - aj | +aj - | Zq - bj | - bj)*Pj + (| Zq - bKq | - (Zq - bKq))* Pqmax,$$

will be replaced by linear form:

$$Cq(Zq) = \sum_{j=1}^{j=Kq}(Uqaj1+Uqaj2-Uqbj1-Uqbj2)*Pj+(2*UqbK2)* Pqmax,$$

where
all aj, bj, Pj, bKq, Pqmax are constants and their sums and products do not influence on optimization.

In (*) equations after optimization will be U…1=0 and U…2>=0,
or U…2=0 and U…1>=0 due to objective and implicit constraints make all variables >=0.

The result can be improved by adding CPs and by allowing higher grade.
Accuracy of the result can be improved by adding density of grid and DTM,
But this increases dramatically number of variables.

2. Centerline optimization (Linear programming approach):
The optimization is reached through linear programming when objective is earthworks total cost; variables are differences between proposal roads elevations and existing topography elevations at all points of grid on right of way; constraints are present roads standards.

This approach takes on account only CPs i.e. points on centerlines of roads system. Grade of road can be changed only at CPs. Recommended to locate CPs at points of centerlines where existing profile changes grade. This will improve optimization process.
On **Fig. 3** is presented vertical existing and proposal profiles of road centerline.
Let S_{ABO} is area of ΔABO, S_{ODC} is area of ΔODC. Then
$S_{ABO} - S_{ODC} = AA' \times (BA + CD) / 2$;

Where
AA' is 2d distance between A and D (later Dij);
AB, DC are **signed** relative proposal elevations at CPs A and D (later Zij);
S_{ABO} is fill quantity;

S_{ODC} is cut quantity;
Objective is: difference between cut and fill volumes calculated for roads centerlines only, i.e. for vertical profiles:

(2.1) $$\sum_{j=1}^{j=K} \sum_{i=1}^{i=Nj} (Di\text{-}1j + Dij)^* Zij \ \text{->} \text{ minimum (or max : see below)};$$

where
K is number of roads; Nj is number of CPs on j-th road of the system;
Dij is 2d distance between adjacent CPs with relative elevations Zij and Zi+1j on j-th road;
D0j = DNjj= 0 per definition;
j = 1,...,K,
i = 1,...,Nj,
To satisfy implicit constraints for all variables: >=0 instead relative elevations we used Zij+10,000. That does not affect on constraints that include only differences of variables, but in objective (2.1) should be added the right hand side member:

$$-\sum_{j=1}^{j=K} \sum_{i=1}^{i=Nj} (Di\text{-}1j + Dij)^* \ 10000.$$

It should be considered for both cases. When objective is negative it must be maximized. When objective is positive it must be minimized. Constraint should be added accordingly:

$$\sum_{j=1}^{j=K} \sum_{i=1}^{i=Nj} (Di\text{-}1j + Dij)^* (Zij +10000) - \sum_{j=1}^{j=K} \sum_{i=1}^{i=Nj} (Di\text{-}1j + Dij)^* \ 10000<0 \text{ or } >0$$

Constraints:

a) Elevations of intersection points of different roads must be same:
Z1j1 + H1j1 – Z1j2 – H1j2 = 0,
Where
1st point of j1-th road coincides with 1st point of j2-th road;
Z1j1 and Z1j2 are proposal elevations at these points;
H1j1 and H1j2 are existing elevations at these points.

b) Grades at all CPs cannot exceed allowable values:
| Zij + Hij – Zi+1j –Hi+1j | / Dij < Gmax,
for j = 1,...,K; i =1,...,Nj.

c) Elevation at each CP should belong to maximal possible allowable interval:

$$Zi0j0 < 10000 + \max \{0, 0.5^*(\max_{i=1}^{i=K} \max_{j=1}^{j=Nj} (Hij - Hi0j0 - Di0j0ij \ ^* \ Gmax)\},$$

and

$$Zi0j0 > 10000 - \min \{0, 0.5*(\min_{i=1}^{i=K} \min_{j=1}^{j=Nj} (Hij - Hi0j0 + Di0j0ij * Gmax)\},$$

for $j0 = 1,\ldots,K;\ i0 = 1,\ldots,Nj$

Where

Zi0j0-10000 is proposal relative elevation at the i0-th point on j0-th road;
Di0j0ij is shortest distance between i0-th point on j0-th road to i-th point on j-th road. This distance is weighted graph shortest distance. Here weights of graph arcs are distances according to road paths. For this purpose we used the Shortest Paths Algorithm that described hereafter in paragraph 8.

3. Centerline optimization (Nonlinear programming approach):

The optimization is reached through nonlinear programming when objective is earthworks total cost; variables are differences between proposal roads elevations and existing topography elevations at all points of grid on right of way; constraints are present roads standards.

This approach also takes on account only CPs i.e. points on centerlines of roads system. It is recommended locate CPs at points of centerlines where existing profile changes grade. This will improve optimization process.

Objective is: total sum of unsigned differences between proposal and existing elevations calculated for roads centerlines only, i.e. for vertical profiles **(Fig. 4):**

A, B, C, D, E are CPs;

AA' is difference between proposal elevation and existing elevation at point A (later Zij).

$$\sum_{j=1}^{j=K} \sum_{i=1}^{i=Nj} | Zij | \to \text{minimum};$$

where

K is number of roads; Nj is number of CPs on j-th road of the system;
Dij is distance between adjacent CPs with relative elevations Zij and Zi+1j on j-th road;
D0j = DNjj= 0 per definition;
$j = 1,\ldots,K,$
$i = 1,\ldots,Nj.$

Constraints:

a) Elevations of intersection points of different roads must be same:
$Z1j1 + H1j1 - Z1j2 - H1j2 = 0,$
Where:
1st point of j1-th road coincides with 1st point of j2-th road;
Z1j1 and Z1j2 are proposal elevations at these points;
H1j1 and H1j2 are existing elevations at these points.

b) Maximal grades at all CPs cannot exceed allowable values:
$| Zij + Hij - Zi{+}1j - Hi{+}1j | / Dij < Gmax$,
for $j = 1,\ldots,K$; $i = 1,\ldots,Nj$.

To transform objective to linear form we use
(3.1.) $Zij = Uij1 - Uij2$,
$Uij1, Uij2 >= 0$,
for $j = 1,\ldots,K$; $i=1,\ldots,Kj$.
So in objective instead $| Zij |$ must be $Uij1 + Uij2$.
In (3.1.) equations after optimization will be $U\ldots1=0$ and $U\ldots2>=0$,
or $U\ldots2=0$ and $U\ldots1>=0$ due to objective and implicit constraints make all variables >=0.
In all constraints also use for Zij its expression (3.1.).

4. Refine:
If CPs are located close each to other (e.g. 10-50m) is recommended to add additional constraints: difference between adjacent road grades should not exceed predefined value per certain distance (e.g. 0.5% per 10m). Then approximate received optimal centerlines by arcs of circles or parabolas or straight lines to satisfy roadway design rules.

If CPs are located far each to other (e.g. 50-300m) inscribe arcs of circles or parabolas between straight intervals according to roadway design rules.

After the solution obtained, start iteration process of moving entire model along axis Z to minimize total cost with taking on account roads cross-sections. The result of optimization is set of CPs elevations that define vertical alignment of entire roads system.

The result can be improved by adding CPs and by allowing higher grade.
Accuracy of the result can be improved by adding density of grid and DTM.

5. Fixed points:
Fixed points means centerline points that must be at definite height. For such points would be added fixed points constraints:
(5.1) $H + Z = E$,

where
Z is relative elevation of the fixed point;
H is existing elevation at this point;
E is required height at the fixed point.
Equation (5.1) take place for each fixed point. It means that each fixed point must be defined as CP. If there are two fixed points or more, in each optimization method, it is necessary to ensure, before optimization, that grades between the fixed points do not exceed the maximal allowable value. This checking must be done for the shortest

distance between fixed points. For that purpose we used the Shortest Paths Algorithm that described hereafter in paragraph 8.

6. Subdivision:

If the optimization process includes earthworks of subdivision lots then it is necessary added to the model the proposal sections and boundaries of lots.

7. **Optimization Algorithm for** excavation material **Transportation:**

After optimization of vertical profiles of roads is done can be received tables of fill-and-cut quantities according to predefined intervals along roads (say, each 50m). So the work program for transportation of excavation material at preliminary planning stage should be created. The invention allows receiving optimal work program. In our model the suppliers are sites with excess of excavation material and demanders are sites with lack of excavation material. The objective is minimum of sum of

excavation weights multiplied by distances:

$$\sum_{i=1}^{i=N} \sum_{j=1}^{j=M} Dij * Xij \rightarrow \text{minimum};$$

where

Xij is the decision variable that means fill quantity will be moved from i-th supplier to j-th demander; $i=1,\ldots,N$, $j=1,\ldots,M$;

where N is number of suppliers and M is number of demanders;

Dij is a shortest distance from i-th supplier to j-th demander; Dij are input data for this optimization process.

Constraints are:

a) Move not more than each demander needs:

$$\sum_{i=1}^{i=N} Xij < Pj; \; j=1,\ldots,M;$$

Pj is fill of j-th demander;

b) Move not more than each supplier has:

$$\sum_{j=1}^{j=M} Xij < Qi; \; i=1,\ldots,N;$$

Qi is fill of i-th supplier;

c) But move all that possible:

$$\sum_{i=1}^{i=N} \sum_{j=1}^{j=M} Xij = \min \left(\sum_{j=1}^{j=M} Pj , \sum_{i=1}^{j=N} Qi \right).$$

The shortest distance between two points is defined through shortest paths algorithm described in paragraph 8.

8. The Shortest Paths Algorithm:

In this invention we used the shortest paths algorithm for Centerline optimization -Linear programming approach (Paragraph 2), fixed points (Paragraph 5) and transportation (Paragraph 7).

DESCRIPTION OF THE DRAWING:

Fig. 1: Scheme of the optimization process.
Fig. 2: Relation between grid and control points for grid optimization.
Fig. 3: Fill - Cut geometrical presentation for centerline linear model objective function.
Fig. 4: Relative proposal unsigned elevations for centerline nonlinear model objective function.

CLAIMS:

1. Using process of **optimization** to obtain the **optimal**: points of intersection, vertical alignment, cross-sections, quantity, cost estimation of the entire project and display result, according to subject plan, **topography**, roads standards and units cost (include different prices for different geologic layers) in **roads** planning.

2. The process of claim 1 wherein "optimization" comprises linear, nonlinear programming.

3. The process of claim 1 wherein Optimal means an objective function that minimizes total cost depends on a set of variables while satisfying some constraints.

4. The process of claim 1 wherein display result comprises 2D & 3D CAD or alphanumeric information.

5. The process of claim 1 wherein Topography comprises DTM, TIN

6. The process of claim 1 wherein Road comprises highway, railway, pedestrian.

7. The process of claim 1 wherein comprises subdivision.

8. Using geologic layers data for the optimization mentioned in claim 1.

9. Using process of optimization for the entire project.

10. Using process shortest paths algorithm for roads system optimization.

11. The process of claim 10 wherein comprises roads system with fix points.

12. Using process of optimization to obtain optimal excavation material transportation.

13. Utilizes the information generated by a computer-aided design (CAD) program as input to the optimization algorithm for road design.

14. Using process of comparison different optimal land use layouts to select the one that minimizes total cost for road design purpose.